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Spatially resolved optical emission spectroscopy of pulse magnetron sputtering discharge

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Abstract

The spatially resolved optical emission spectroscopy of various species of a pulse DC unbalanced magnetron sputtering is studied. Ar–N_2 gas mixtures are used. Emission lines corresponding to titanium cathode and gas discharge species are considered. In this study, the two-dimensional (2-D) emission profiles of the lines are measured by an ICCD camera during TiN coatings. It turns out that the 2-D emission profiles of the various lines behave differently. As a result, we obtained the surface roughness value of RMS 2.3 nm at higher pulse frequency and 3.8 nm at lower pulse duty cycle.

Keywords: Pulsed plasma; Reactive magnetron sputtering; Spatially resolved OES

1. Introduction

At present, magnetron sputtering is a well-established technology, currently used for the deposition of a variety of thin films. Typical applications include display, semiconductor, hard coatings, decorative coatings, optical coatings, and so on [1,2].

In the 1990s, interest in pulse magnetron sputtering was on the rise [3,4]. Pulsed magnetron sputtering combines the advantages of conventional DC magnetron sputtering technique and RF magnetron sputtering technique.

The pulse regime gives a higher stability of the discharge in reactive gases. Pulse magnetron sputtering reduces substrate temperature due to decreasing duty cycle, but stimulates chemical reaction on coated surfaces due to increasing plasma density and ion energy [5–8].

The influence of process parameters such as pulse frequency and duty cycle on the growth mechanism of thin films has been investigated by many researchers [9–12]. However, a full understanding of pulse magnetron sputtering is poor. Properties of films deposited by magnetron sputtering are strongly influenced by the energy of particles and ion density arriving at substrates. In particular, ion bombardment of the substrate has an influence on film growth and properties such as microstructure, crystallography, and mechanical properties.

Several methods exist to measure plasma characteristics during discharge. The different species present and plasma parameters in the plasma have been studied by electrostatic probes, which measure ion density, electron temperature, and plasma potential; and optical emission spectroscopy (OES), which can be used for identification of species in the plasma; laser-induced fluorescence (LIF); and absorption spectroscopy [13]. In plasma processing technology, optical diagnostic methods have proven to be the most valuable by far, both in the applied area and basic science area. Among diagnostic tools, OES is important because of its non-intrusive character. However, OES generally measures integrated emission, or emission coming from a limited zone of plasmas. Since magnetron sputtering discharges are spatially inhomogeneous, spatial distribution of each species in the plasma is important. Thus, spatial distribution was measured by the spatially resolved OES. This is now a well-established method [14–17].

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In this study, a pulse unbalanced magnetron sputtering was employed to synthesize TiN films. We deal with pulse parameters such as pulse frequency and duty cycle in argon–nitrogen plasmas. Two-dimensional (2-D) emission distributions of spectral lines are measured by an ICCD camera during TiN coatings. Emission lines corresponding to titanium cathode and gas discharge species are considered. The surface morphology was analyzed by atomic force microscopy (AFM).

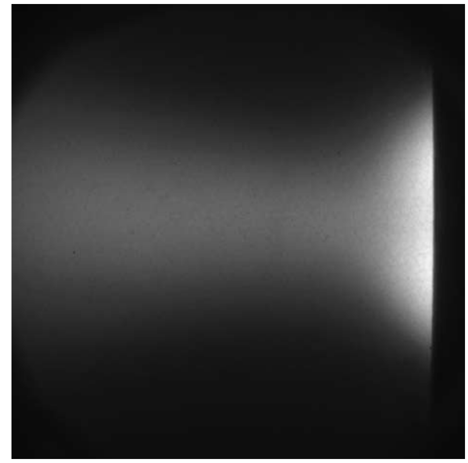
2. Experimental details

Fig. 1 shows the experimental set-up of the system. The magnetron sputter has a cylindrical form so that its unbalanced magnetic field between the outer annular pole and an inner cylindrical pole is axially symmetric.

TiN films were deposited on Si(100) wafers by magnetron sputtering of circular Ti with a target of diameter 50 mm. The target was cooled by water circulation. The magnetron discharges were operated by a pulse DC power supply under the following conditions: average discharge current of 600 mA, argon partial pressure P_{Ar} of 3 mTorr, and nitrogen partial pressure P_N of 0.2 mTorr at all conditions. The pulse frequency varies between 10 and 50 kHz. Also, the pulse duty cycle varies between 20% and 90%. As the pulse frequency and duty cycle are changed, the Ti target voltage is adjusted in order to keep the same discharge current. The target-to-substrate distance is 50 mm, and the substrate is electrically floating.

The 2-D emission distributions of the spectral lines are measured by an ICCD camera (PI-MAX:512; Princeton Instruments) during TiN deposition. The images of each species in the plasma are captured through the viewing

(a) Ti I



(b) Ti II

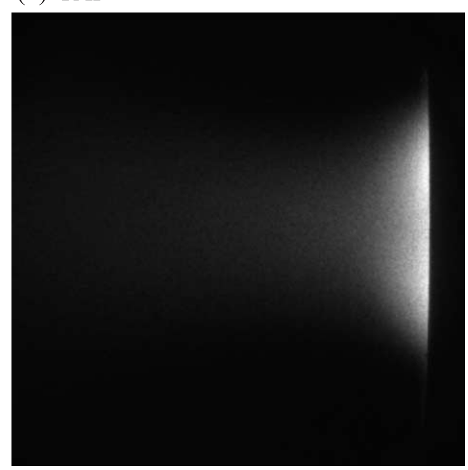


Fig. 2. ICCD images of emission intensity of Ti I (a) and Ti II (b) in pulse magnetron sputtering process, with 3.2 mTorr pressure, 10 kHz, and 50% duty cycle. The discharge power is 9 W/cm^2.

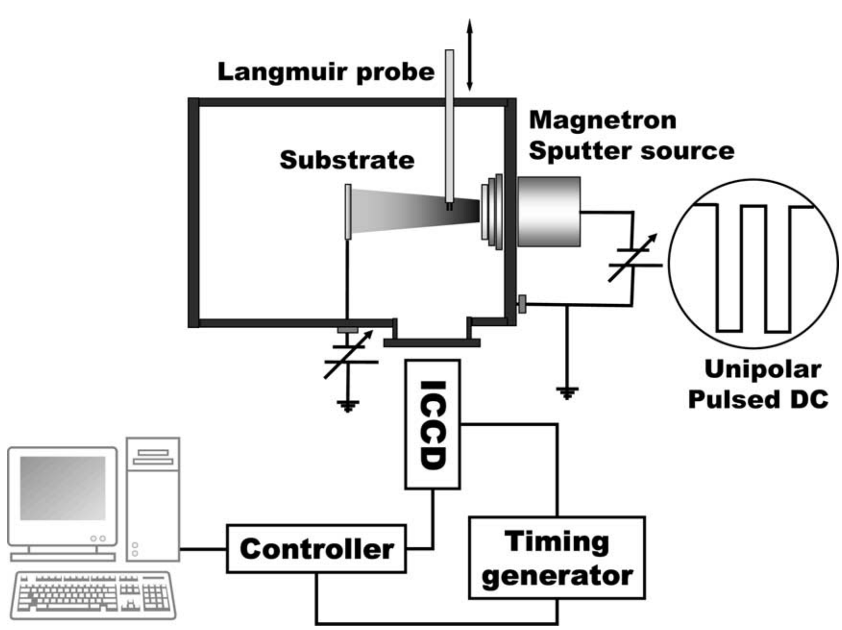


Fig. 1. Schematic diagram of experimental apparatus and systems.